Arctic Climate Connections Curriculum: A Model for Bringing Authentic Data Into the Classroom

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ABSTRACT

Science education can build a bridge between research carried out by scientists and relevant learning opportunities for students. The Broader Impact requirements for scientists by funding agencies facilitate this connection. We propose and test a model curriculum development process in which scientists, curriculum developers, and classroom educators work together to scaffold the use of authentic, unprocessed scientific data for high school students. We outline a three-module curriculum structure that facilitates these goals. This curriculum engages students in the collection, description, visualization, and interpretation of data; develops understanding of the nature of science; includes prompts to develop higher-order thinking skills; builds knowledge of regional relevance of climate change in students; uses active learning techniques; and can be easily integrated with the Next Generation Science Standards. The curriculum was reviewed and tested in the classroom. To shed further light on the curriculum development process, we gathered reflection data from the scientists, curriculum developers, and educators. Scientists appreciated the collaborative process in which they contributed their expertise without requiring a large time commitment or strong expertise in science education. The curriculum developers viewed the modular structure as helpful in breaking complicated scientific concepts into teachable steps. Classroom educators appreciated the detailed description and step-by-step instructions to navigate data analysis tools like Excel or Google Earth. Initial classroom implementation of the curriculum by 11 teachers with over 1,100 students showed high levels of interest in the topic and engagement. Further work is needed to assess efficacy of the curriculum through classroom observations and measures of student learning. © *2015 National Association of Geoscience Teachers*. [DOI: 10.5408/14-030.1]

Key words: curriculum development, Broader Impacts, climate education, Arctic, data, inquiry, professional development workshop, Excel, Google Earth

INTRODUCTION

As human activities touch Earth's dynamic systems with an increasingly large footprint, the need for robust scientific literacy among the citizenry is becoming ever more urgent. This is particularly true with regard to climate science (Ledley et al., 2014; Melillo et al., 2014; Petes and Hubbard, 2014). Ideally, scientists and educators work together to translate new research findings into common knowledge (Handelsman et al., 2004; Scotchmoor et al., 2005). Thus, funding agencies require scientists to make their findings and data publically available. The National Science Foundation's (NSF's) Broader Impacts criteria are an essential part of scientific research projects (NSF, 2015a). However, broadening the impact of science research beyond the scientific community can be difficult for researchers. Using teams of both researchers and science educators has been shown to be an effective strategy to collaboratively develop and disseminate relevant learning materials for students and citizens (Ledley et al., 2008, 2011, 2012; Bodzin et al., 2014; Houseal et al., 2014). Educators form the critical link from the scientists to learners in building science literacy (Dupigny-Giroux, 2010).

The Next Generation Science Standards (NGSS; NGSS Lead States, 2013) help frame geoscience education by stressing a three-dimensional approach for teaching content knowledge, scientific practices, and cross-disciplinary concepts. By integrating all three dimensions into the curriculum design process, educators can create materials that foster students' critical thinking skills and develop scientific habits of mind. Ideally, geoscience content knowledge and observations of geologic processes can be combined to develop a coherent mental framework that allows students to reason about Earth (Kastens and Manduca, 2012). In addition to content knowledge, students need to develop an understanding of how scientists know what they know (Hannula, 2003; Laursen and Brickley, 2011). While the scientific practices may differ slightly among the geoscience subdisciplines (Manduca et al., 2002; Manduca and Kastens, 2012), all follow a common scientific process (Hannula, 2003). The controversial and contentious debates around topics like evolution and climate science are often mired in misconceptions about the nature of science and the scientific process (Carter and Wiles, 2014). Therefore, educational materials around climate change topics need to clearly describe how scientists acquire data. A scientifically literate person also holds basic quantitative reasoning skills (Mac-

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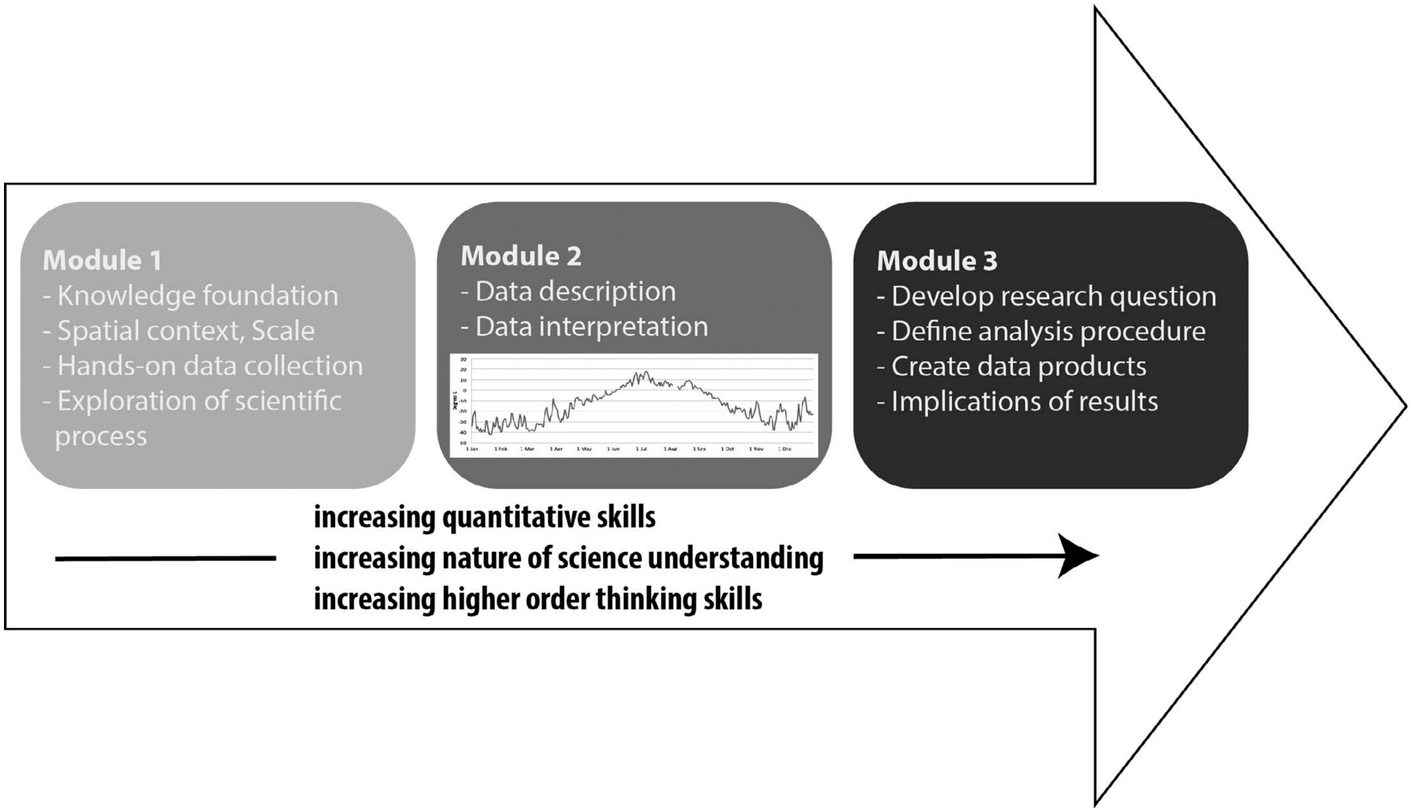

FIGURE 1: Model design structure of curriculum to scaffold use of authentic scientific data.

donald et al., 2000; Hancock and Manduca, 2005; Manduca et al., 2008). In order to build quantitative skills and to develop students' understanding of scientific results, learners need experience with the analysis, description, and interpretation of data (Handelsman et al., 2004). Finally, geoscience disciplines require students to orient observed phenomena and processes in space and time and apply cross-disciplinary scientific concepts—referred to as crosscutting concepts by NGSS.

Despite calls to strengthen students' quantitative skills (Manduca and Mogk, 2003; Ledley et al., 2008; Taber et al., 2012), the use of authentic, minimally processed scientific data in K–12 classrooms is rare. Some geoscience education programs successfully engage students in working with authentic data (Means, 1998; Ledley et al., 2012; Ellwein et al., 2014), but often students are not introduced to unprocessed numerical data until postsecondary education.

Here, we describe a high school curriculum that was developed using a three-way collaborative process. Research scientists provided their data and supporting information to a team of curriculum developers. The curriculum development team designed three instructional models, with input from the scientists. Lastly, classroom educators were brought into the process to review and test the instructional materials. This process yielded a well-rounded curriculum that highlights the use of authentic scientific data in a way that is accessible to high school students.

We initially outline the curriculum we developed with this process to provide foresight of the project product. We then describe the process we used to create and refine the teaching materials and teachers' guides. We present results in two areas: the way in which scientists, curriculum developers, and classroom educators engaged in the collaborative model of curriculum development and the data from the classroom implementation of the Arctic Climate Connections (ACC) curriculum.

THE ACC CURRICULUM

We propose a three-module curriculum structure to effectively scaffold the use of raw scientific data in classrooms (Fig. 1). The ACC curriculum follows this structure and is composed of three modules that contain multiple activities and resources. The curriculum was developed for high school science students. The curriculum is aligned with the NGSS, the Climate Literacy Principles (USGCRP, 2009), and the Colorado Science Standards.

Module 1: Exploring the Arctic

A first module builds the knowledge foundation around the location and the phenomenon that is studied and introduces students to data and the scientific process through hands-on data collection activities.

The ACC curriculum begins by helping students understand what the Arctic is. Students review what they already know about the Arctic via concept mapping and by discussing different definitions of the Arctic. Students build an understanding for the Arctic environment through exploration of Arctic vegetation. They then explore the Arctic's indigenous population through different media and learn about the role that indigenous people play in studying Arctic climate.

In the next part, students set out on a virtual tour of the Arctic using Google Earth. They start at their home school and then "fly" to Arctic Canada, where they explore Eureka's meteorological station. The Eureka research site (80.0° N, 85.9° W), near the coast of the Arctic Ocean located in the Canadian territory of Nunavut, is a long-term research observatory for monitoring the changing Arctic climate. Turbulent fluxes and mean meteorological data are continuously measured and reported hourly at various levels on a 10-m flux tower (Grachev et al., 2012). Data collected here is used in later modules.

Students experiment with the distance measure tool, the daylight–nightlight function, and the time travel tool, and they explore available photos and information available on Google Earth. From Arctic Canada, students take a circum-Arctic trip to other research stations in Alaska, Svalbard, and Russia before connecting the information from these different sites into a cohesive vision of the characteristics of the Arctic.

In the third part of this introductory module, students collect their own meteorological data in hands-on activities. Students form multiple "research teams" to collect albedo, relative humidity, and soil temperature data outside their school. Using a jigsaw approach (Aronson, 1978), the students reorganize into "expert teams" to debrief the data collection and engage in discussions based on follow-up questions. This activity concludes with students learning about the specific instruments that are collecting similar data at the Eureka meteorological tower. Students' understanding of data collection is refined with additional questions, such as the difference between accuracy and precision. An extension activity introduces students to the use of the freely available ImageJ software for conducting albedo measurements.

Module 2: Do You Really Want to Visit the Arctic?

A second module exposes students to data interpretation. Students are provided with data products, generated from raw scientific data. Students read graphs, explore other types of data products, describe the data, and draw conclusions.

The second module of the ACC curriculum begins with a warm-up exercise in which students read the National Oceanic and Atmospheric Administration's (NOAA's) State of the Climate report and then formulate questions they have about the Arctic. This activity helps students gain experience in forming research questions and hypotheses.

The main portion of this module is a jigsaw activity to analyze existing meteorological datasets from their Arctic study site in Eureka. Students form "research groups" to learn about a specific weather parameter (air temperature, wind speed, snow depth, and incoming solar radiation). The research groups describe annual variation of "their" parameter based on graphs that show 1 year of data from Eureka. Students then shuffle to form "research teams." Each research team is assigned a different purpose for visiting the Arctic, such as (1) testing fat-tired bicycle performance on snowy surface for field research, (2) collecting seeds from Arctic wildflowers, (c) conducting astronomy research and photographing the night sky, or (4) engaging in annual maintenance of meteorological instruments at research stations. The research teams consider each meteorological parameter in determining the best time for their research mission to the Arctic. Because each team has a different mission, they come up with different answers. For example, a team that needs to photograph the night sky would not be able to visit the Arctic in the summer due to perpetual daylight. Lastly, students work individually to consider when they, personally, would want to visit the Arctic. An optional follow-up activity involves a group project to create an infographic that illustrates the weather in Eureka.

Module 3: Exploring Arctic Climate Data

Students are now ready to process the raw data; thus in a third module, they create data products. This is also the place where the implications of results at larger scales or global teleconnections or implications can be explored. In this module, students develop a research question, process and analyze data, and draw conclusions.

In the final module of the ACC curriculum, students examine some of the complexities of Arctic weather. The first part of this module illustrates the concept of albedo. Students use a yearlong dataset of incoming and outgoing radiation collected in Eureka to calculate albedo values and see how albedo varies through the year. Next, students delve into numerical datasets. Using step-by-step instructions and screenshots, students use Excel to create line graphs of springtime temperature, snow depth, and albedo. Once the graphs are plotted, students can examine the relationships among these parameters and can use the data to explain why the snow depth decreases rapidly in early summer. Students then create a concept sketch and write short essay to synthesize what they have learned about albedo and its relationship to climate.

The final part of the module asks student to use paired imagery from the Arctic to compare changes in albedo over the past 100 years. The takeaway message emphasizes how decreasing albedo is a self-reinforcing feedback mechanism in the climate system. In two follow-up activities, students can deepen this understanding. The first uses images and data from Greenland to further examine albedo changes on the Greenland Ice Sheet. The second activity examines a case study from Colorado in which dust layers on the snowpack have implications for melting, runoff, and water supply management. This case study brings the topic back to a local context and ties into public policy and the search for solutions.

CURRICULUM DEVELOPMENT PRIORITIES

We were guided in the development of the curriculum by six priorities (Fig. 2). The curriculum had to (1) strengthen students' quantitative skills through working with authentic scientific data, (2) scaffold the curriculum in a way that allows students to develop an understanding of the scientific process, (3) include prompts to develop higher-order thinking skills, (4) make the topic relevant to students' lives through comparison between their local conditions and the Arctic while connecting to global climate processes, and (5) provide teachers with a classroom-ready, modular curriculum that includes assessments, answer keys, and supporting materials but allows for individual adjustments and selection of components to best suit the needs of educators.

Strengthening Quantitative Skills With Data-Driven Learning

Since the late 1990s, the geoscience education community has undertaken a renewed effort to strengthen the

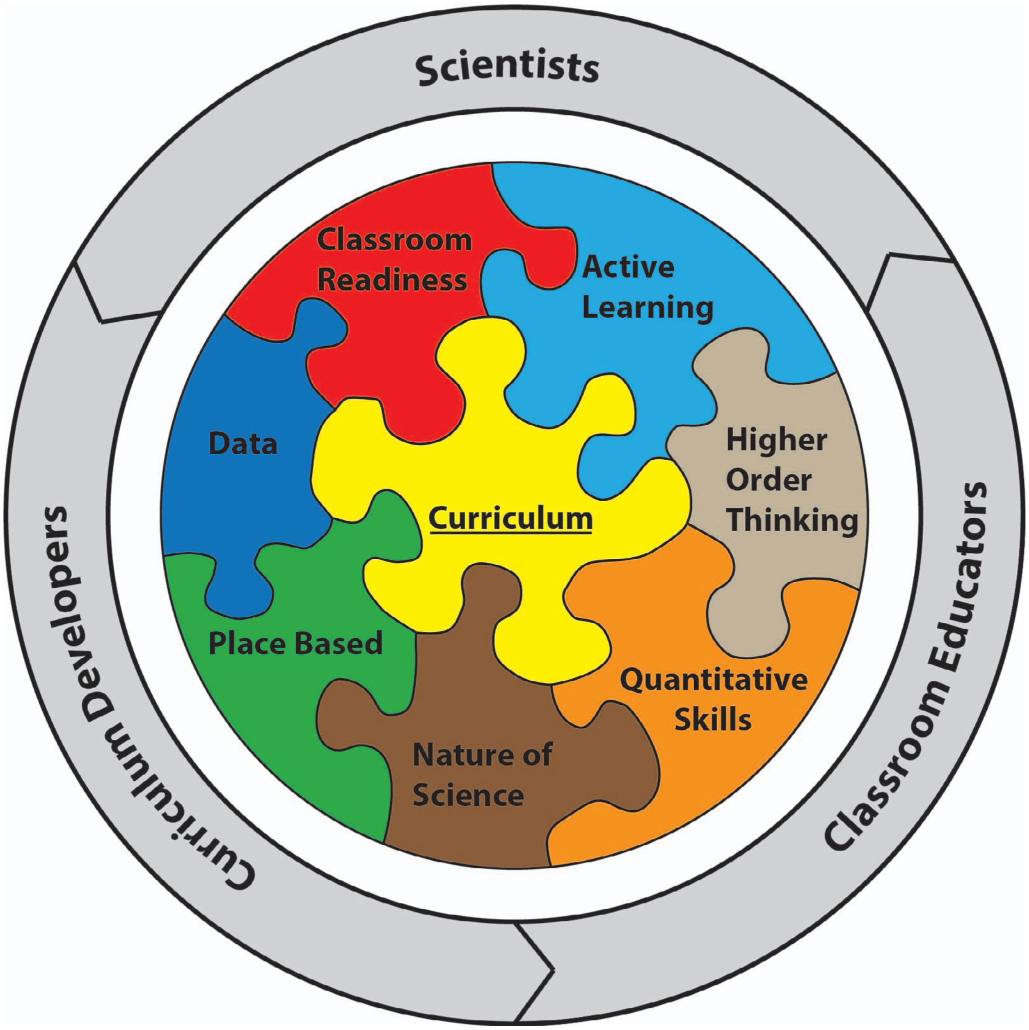

FIGURE 2: The collaborative curriculum development model. Six priorities and the authentic data form the key features of the model curriculum. The outer circle shows the interaction of the three collaborators.

quantitative aspects of geoscience education, to expose students to real data, and to prepare students for the quantitative aspects of the discipline—but mostly at the postsecondary level (Macdonald et al., 2000; Manduca and Mogk, 2003; Hancock and Manduca, 2005; Manduca et al., 2008). Examples of precollege programs that expose students to real data include the international Global Learning and Observations to Benefit the Environment program (Means, 1998; Butler and MacGregor, 2003), which aims to introduce secondary students to real scientific data through data collection, and the AccessData project (Ledley et al., 2012; Taber et al., 2012), which scaffolds the use of data tools through step-by-step instructions. Many data-rich learning activities include steps in which students work with data products like images, graphs, and output of data tools; however, few such activities involve minimally processed authentic datasets.

A key theme in the development of the ACC curriculum was that of data-driven learning. That said, the target audience of high school students cannot typically be expected to dive into a complex Excel dataset without becoming overwhelmed or discouraged by the challenge of the work. In some cases, teachers lack proficiency or only have time to use well-described activities with answer keys. Thus, the ACC teaching materials are thoroughly scaffolded, with each segment of the curriculum building deliberate connections to collecting, understanding, and synthesizing data (Fig. 1). Moreover, the relevance of the data is clearly established. Why should a high school student be concerned with shortwave radiation on Ellesmere Island? We built in several opportunities for students to learn about the Arctic environment, engage in role-playing activities, and compare Arctic weather to that in their hometown. By the time students sit down to work with the Excel data, they have had multiple opportunities to understand both the relevance of the data and the mechanics. Teachers are provided with detailed step-by-step instructions for using data tools like Excel or Google Maps that they can use for their own reference only or in class to guide students if necessary.

Engaging Students in the Nature of Science

The understanding and appreciation of the nature of science and how scientists know what they know is the basis for a constructive dialogue between the public and the scientists (Laursen and Brickley, 2011); therefore, we highlight this as a key learning goal for students (National

Research Council, 2012; NGSS Lead States, 2013, appendix H). Since the ACC curriculum uses the work of researchers in the Arctic, we took this opportunity to develop an understanding of the scientific process engaged by these researchers.

Throughout the curriculum, we stress inquiry approaches. We build understanding for the nonlinear and often circular nature of the scientific process (Laursen and Brickley, 2011). In the first module, students conduct hands-on measurements of albedo, relative humidity, and soil temperature, which exposes them to the data collection aspect of the scientific process. They record and interpret their data, and they are asked to interpret the meaning of their data and how they fit into larger questions. For example, the albedo "expert team" discusses the effect of volcanic eruptions on global climate—prompting them to discuss planetary albedo. After completing their measurements, students learn about the instruments at the meteorological research station in Eureka, Canada. In the activity, students are prompted to consider the logistics of data collection in a remote environment.

In Module 2, students start out by developing research questions related to Arctic climate. With this mindset of asking questions, they explore and describe data plots from the 2010 data collection campaign in Eureka. Students use graphs of air temperature, wind speed, incoming shortwave radiation, and snow depth and engage in a jigsaw activity to synthesize seasonal patterns in Arctic weather.

Modules 1 and 2 set the stage for the third module, in which a research question is posed and students delve into the datasets to unravel the processes involved in the rapid thinning of the snowpack in early summer. Lastly, processes learned are applied to the larger context of global climate. The data include some measurement artifacts and a hiatus in data collection when the instruments were calibrated. The teacher's guide contains the necessary background to help educators understand these nuances and prompts them to use these examples as teachable moments about the interpretation of raw data.

Creating Opportunities for Higher-Order Thinking

The hierarchy of learning is often described based on Bloom's taxonomy (Bloom et al., 1956; Anderson and Krathwohl, 2001); here, remembering is the foundation of learning and the lowest cognitive level and is followed by understanding and applying, each step advancing the cognitive demand. Higher-level thinking skills are the top three levels of the pyramid of learning—from analyzing, to evaluating, and finally, the highest cognitive skill, creating. Activities that address higher-order thinking skills are more interesting and engaging for students and educators, but they also require significant scaffolding to be successful for learners of all abilities.

Opportunities for higher-order thinking were built into each part of the curriculum. While some of the activities involve simple measurements, calculations, or questions, students are also challenged to compare, analyze, or synthesize the material in each module. Some examples include evaluating the expertise of the authors, funding source, and reliability of the materials; interpreting the effect of Earth's axial tilt on Arctic climate and a dust storm on the albedo of an ice sheet; determining the optimal timing for an Arctic research mission, comparison of Arctic to hometown weather, and development of a definition for winter; and analyzing the linkages among datasets, exploring albedo as a positive feedback mechanism, and developing scenarios for the role of albedo on the global climate. The higher-order questions always include questions for different levels of understanding, allowing a teacher to differentiate their instruction if necessary.

Improving Relevance by Tying the Arctic Environment to Students' Home Environment

The idea of global climate change is an abstract concept to many students—a practical understanding requires global thinking that is difficult for students (Wilbanks and Kates, 1999). Often, a cold spell in local weather is used as proof that climate change is not happening, or extreme heat waves raise public "belief" in climate change (Lombardi and Sinatra, 2012; Leiserowitz et al., 2013). Another challenging concept for educators and students alike is how changes in the Arctic can affect the global climate system. Ideally, climate education ties into students' lives and local environment (Semken and Freeman, 2008; Schweizer et al., 2013).

In this curriculum, we attempt to tie the learning to students' lives. For example, in Module 1, students explore the Arctic using Google Earth, but they start with exploring their school environment before "flying" to the Arctic. In Module 2, students exploring Arctic climate data are asked to find comparable data for their hometown through NOAA's Climate Data Online (NOAA, 2015). In Module 3, students tie the concept of localized albedo to an understanding of the effects of decreasing regional albedo on the global climate. Establishing the link for how Arctic climate affects climate globally and therefore affects the local climate is critical, especially for students who live far away from Arctic or alpine environments. The curriculum provides some guidance on how to build this connection.

Pedagogies, Assessment Strategies, and Types of Activities

Educational research findings suggest that an active learning environment promotes the growth of critical thinking skills and improves learning outcomes (Hake, 1998; McConnell et al., 2003; Prince, 2004). Ideally, effective learning experiences include a variety of activities to serve students with varying academic strengths and learning styles.

The ACC curriculum includes a range of activity types, including visual, oral, written, quantitative, group, and individual. For each activity, learning goals are clearly outlined. Relevant background information and tips are provided for teachers who are using a technique for the first time. See Table I for types of instructional methods used throughout the curriculum.

Usability and Classroom Readiness

Many educators prefer classroom-ready materials that they can easily modify for their individual needs. For the curriculum to be implemented in a variety of educational settings, the materials should be readily usable by a busy teacher. Curriculum reviewers involved in this project reinforced this point, and the materials were revised to improve usability.

TABLE I: Pedagogies and assessment strategies used in the ACC curriculum.

Module 1: Exploring the Arctic
• Concept mapping
• Crumple-and-toss game to reach group consensus
• Use of interactive online tools such as UNEP[1] interactives
• Google Earth—technology integration
• Taking hands-on measurements of meteorological parameters
• ImageJ software for direct albedo measurements
Module 2: Do You Really Want to Visit the Arctic?
• Jigsaw with role playing
• Individual reflection
• Development of infographics
Module 3: Exploring Arctic Climate Data
• Making calculations from data
• Graphing with Excel and data analysis
• Concept sketch
• Scientific writing
• Interpretation and drawing inferences from aerial images

[1]UNEP = United Nations Environment Programme.

Separate documents were created for teachers that contain goals, teaching tips, alignment with the NGSS and Colorado science standards, suggestions for follow-up activities, background readings, and related materials. Student guides contain step-by-step instructions, links to relevant Web sites, and screenshots for complex tasks like navigating Google Earth or creating Excel graphs. The student guides were designed to be reused by multiple students to reduce demand for photocopying, while each student uses a simple worksheet to be turned in for assessment. All imagery for each module is also provided in a separate PowerPoint file for printing or in-class slideshows. Excel files are provided for both instructors and students, with the instructor version containing pre-made graphs and the student version containing the data only. Thus, the materials for both teachers and students were all designed and organized with real-world usability in mind.

CURRICULUM DEVELOPMENT MODEL PROCESS

The ACC curriculum uses authentic data from an Arctic research project focusing on surface energy balance at multiple circum-Arctic study sites (Surface Energy Budgets at Arctic Terrestrial Sites). The datasets used in this curriculum were collected in 2010 at the NOAA meteorological tower in Eureka, Nunavut, Canada. While the curriculum described here is built around Arctic meteorological data, the collaborative curriculum development model, as well as the model structure of the curriculum, can be applied to many authentic geoscience datasets and research questions.

Collaborative Curriculum Development Model

Collaboration is integral to creating a curriculum that begins with complex scientific research and ends with a refined educational product. Of all of the participants in the development process, no individual possessed sufficient skills to develop the curriculum from start to finish. Thus, the ACC curriculum was developed through an iterative collaboration among research scientists, curriculum developers, and classroom educators (Fig. 2). We refer to this process as the collaborative curriculum development model (Figs. 2 and 3).

Here, we use the ACC curriculum as an example to describe the collaboration model (Fig. 3): The process begins with the research scientists (Grachev and Persson), who provided the raw data and scientific guidance. During an initial meeting with the curriculum development team, the scientists shared information about their research project, the data they collect, and the key study findings. Curriculum developers used this information to brainstorm the goals and outline of the curriculum. The curriculum developers then outlined a modular design of the curriculum (Fig. 1) to lead students through the important steps of working with the data: data collection, data description, data analysis, and data interpretation. This design also allows flexibility for teachers

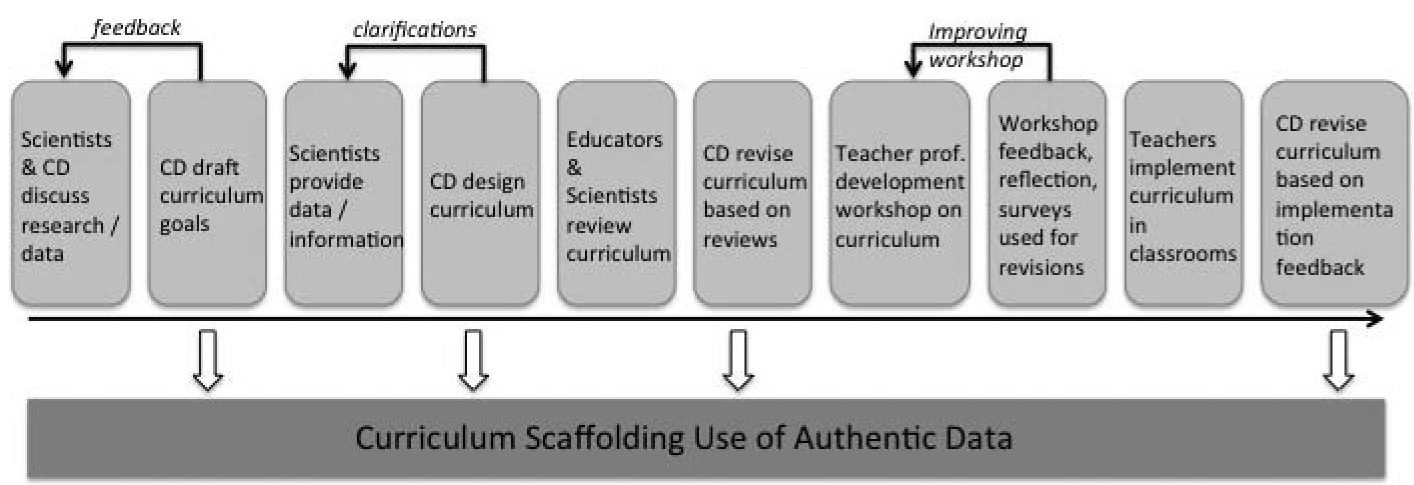

FIGURE 3: Flow of collaborative curriculum development process (CD = curriculum development team).

to either use the whole curriculum or select parts of it to meet the needs of their students. Throughout this process, the six priorities outlined earlier were woven into the final curriculum (Fig. 2). Four master teachers reviewed the curriculum draft (two middle school and two high school level) and revisions were made based on their feedback. The research scientists completed a scientific review of the curriculum.

The revised curriculum was then presented to science educators during a 1-day workshop. This workshop served a dual purpose of showcasing the curriculum to educators and giving real-world feedback to the curriculum design team. The overall design of the workshop put the educators in the role of students and allowed them to engage in the active learning approaches used throughout the curriculum. Educators were grouped by grade level for discussions of implementation strategies for their audience. The two research scientists gave an interactive lecture on the science of the Arctic and the realities of collecting data in the Arctic in an extreme environment. Their lecture was recorded and made available online as a resource for classroom use. The scientists were available to answer questions and talk informally with the participating teachers and science educators.

Based on the workshop experience, the curriculum developers made additional revisions to the curriculum. Some workshop participants implemented the curriculum in their classrooms and provided additional suggestions for changes to the curriculum. Their revisions were incorporated into the final version of the curriculum.

A total of 26 classroom educators and 2 informal educators, from 19 Colorado schools, participated in the 1-day workshop. The workshop was advertised for high school educators through relevant e-mail lists and the workshop was open to all educators. Most participants were teaching in the K–12 system (seven elementary school, nine middle school, and seven high school teachers), but some were college level educators (three) or informal educators (two). Elementary and middle school educators explained their interest in the high school curriculum as arising from the lack of data-rich resources for their grade level and from the bulk of precollege Earth Science being taught in elementary and middle schools. In our work, students were only involved insofar as teachers enacted particular ACC modules in their classrooms. We only report from the teachers' perspectives as they have implemented the curriculum in their classes.

Information about the workshop participants, the workshop, and the curriculum was gathered in pre- and postworkshop surveys. A survey was administered to the workshop participants 2 weeks before the workshop, and another was administered immediately following the workshop. All workshop participants completed the surveys. The survey was developed to measure four constructs: (1) personal views on global warming, (2) climate content knowledge, (3) nature of science understanding, and (4) quantitative skills (Table II). We strived to include questions from most levels of Bloom's taxonomy, from basic knowledge questions to evaluation questions (Anderson and Krathwohl, 2001). The survey contained questions created specifically for the ACC workshop, along with questions derived from others (Leiserowitz et al., 2011; Gormally et al., 2012; Morrow, 2013). The surveys (see supplemental material, which can be found online at http://dx.doi.org/10.5408/14-030s1) included 14 questions that were asked both before and after the workshop (11 multiple choice and 3 open-ended questions). In addition, 7 questions inquired about the participants' teaching environment, their student population, and their approach to teaching with data (presurvey only), and 4 questions asked participants to reflect on the workshop experience (postsurvey only). During the workshop, participants provided regular feedback on the curriculum design, implementation strategies, and other ideas through feedback cards and discussions. Of the 26 workshop participants, 11 teachers provided feedback on an eight-item implementation survey about their classroom implementation. These 11 teachers implemented the curriculum or parts of it with over 1,100 students (110 college level, 225 high school level, 595 middle school level, and 200 elementary level) between March 2014 and March 2015.

The research scientists completed a reflection survey about their experiences in the program. Similarly, all seven science educators who were part of the curriculum development team (e.g., curriculum developers, reviewers, and workshop presenters) completed a final survey about their experiences in the development of the ACC curriculum. Due to the small number of both scientists (two) and science educators (seven) involved, we engaged in qualitative descriptions instead of statistical displays to describe the experiences of these participants. Our qualitative descriptions are primarily short excerpts of survey responses or summaries, which are provided in the results section to offer a sketch of the collaborators' experiences.

The responses to all surveys were analyzed using descriptive statistics. The open-ended responses were analyzed following standard qualitative analysis techniques (Miles and Huberman, 1994; Maxwell, 2005), and the scaled responses were analyzed using basic descriptive statistics. The open-ended responses were coded using a grounded coding method (Glaser and Strauss, 1967). One researcher did this initial coding and developed a codebook of emerging themes. Then, both the initial coder and another researcher coded all data. They obtained 91.3% interrater reliability; they then consensus-coded the data in which the coding agreement was lower than 80%, following the initial, master coder for any of the codes above 80% agreement.

CURRICULUM DEVELOPMENT MODEL RESULTS

We proposed and tested a collaborative curriculum development model process and structure for scaffolding authentic scientific data for the use with precollege students. Here, we report on the curriculum experiences of developers, scientists, and educators with this process and their reflection on the model design. We also provide data from classroom implementation of the ACC curriculum.

Curriculum Developers and Curriculum Reviewers

The curriculum developers initially attempted to build the curriculum around new research findings that were unveiled by the Surface Energy Budgets at Arctic Terrestrial Sites project, trying to literally broaden the impact of the new research findings. However, the curriculum development team realized quickly that building a curriculum

TABLE II: Results of pre- and postworkshop surveys from 26 workshop participants. Survey results were aggregated under four constructs.

Constructs	No. Items	Pretest Results	Posttest Results	Notes
Global Warming (GW) personal stance	2	42% "believe" that human activity causes GW; 89% think that scientists agree GW is happening	Shift of participants toward "believing" human activity causes GW and that scientists agree GW is happening	
Climate content	5 MC[1] questions	75.8% correct	88.4% correct	1 question that required applying albedo knowledge showed a decrease in correct answers by 10.5%
	2 open-ended questions	Increase in complexity and detailed information in responses of 13% (albedo reasoning) and 63% (Arctic definition)		
Nature of science	3	59.6% correct	70.2% correct	
Quantitative skills	1	73.7% correct	68.4%	One respondent switched from the correct to the incorrect answer
	1 open-ended question	Increase of 12% in complexity and detailed information in responses (graphical depiction of data)		

[1]MC = multiple choice.

around cutting-edge research findings was too complex for students and chose to focus on foundational science concepts like albedo and Arctic climate. The curriculum developers found that brainstorming sessions with the scientists were important for the curriculum development process and their understanding of the data. Both curriculum developers felt that they were satisfied with the level of interactions with and input from the scientists. Once the scientists had reviewed the curriculum outline and the data were disaggregated, the development team did not request more input from the scientists until a final scientific review; this minimized the impact on the scientists' time.

Defining the three-module structure (Fig. 1) and the six priorities of the curriculum (Fig. 2) allowed the curriculum development team to scaffold the pedagogy of each module deliberately, using backward design (Wiggins et al., 1998) from the learning goals to the activities. Both curriculum developers emphasized that bouncing ideas and revisions off each other was an integral part of the process and both helpful and satisfying.

The curriculum developers found the reviews from classroom educators helpful in the curriculum development process. When asked to reflect on their experience with the development process, the four curriculum reviewers found the review process to have been satisfying and well organized. They stressed that working with a polished draft instead of an unfinished document was important to them. Curriculum reviewers mentioned that being able to use the review function in a word processor made the reviews easy. They also appreciated that their work was compensated ($75) and that the curriculum development team incorporated their suggestions into the final curriculum.

Research Scientists

The research scientists found the iterative curriculum development process to be constructive and productive:

> *"The developers came into the meetings with a balanced combination of open-mindedness and preconceived ideas to effectively guide the discussions. The former allowed the developers to listen to what we felt we had to offer and the latter helped guide the discussions towards a curriculum that was feasible to develop."* (O. Persson, reflection survey)

In their reflections, the scientists highlighted that limiting the time commitment to productive, significant conversation was important. While they enjoyed providing insight into the science around the datasets, they appreciated that the curriculum development team was able to quickly understand the science and data in a way that allowed them to develop a curriculum without a lot of guidance.

The scientists also stressed that wide curriculum dissemination was important to them and their funding agencies. Scientists are used to measuring success through dissemination of research findings. The scientists mentioned that the time and effort they invested into the curriculum seemed "worthwhile" because of the curriculum's wide reach. They appreciated the open dissemination through Web sites, as well as the workshop and conference presentations about the curriculum. The ability to measure and report the project reach through Web statistics was also helpful.

The scientists enjoyed their participation in the workshop and wished that they had participated in the workshop for more than just their presentation. They pointed out that the range of understanding of science and the curriculum topic varied among the participating teachers, requiring the scientists to adjust the level of detail and complexity when responding to their questions:

> *"The teachers appeared to be genuinely enthused to be part of the workshop and interested in the material."* (O. Persson, reflection survey)

TABLE III: Quotes from workshop participants.

• "Super cool for kids to see Eureka tower and learn about how data actually taken. This part is usually forgotten and kids just 'accept' data and have no understanding of how data was gathered." (Quote from a feedback card during workshop)
• Best things about today's workshop: "I am going to school with activities that I can use almost immediately." (Quote from postworkshop survey)
• Best things about today's workshop: "Working through the activities was very helpful for me to see how I can really implement them in my classroom. I love that [one of the presenters] kept bringing the conversation back to how to implement and facilitate in the classroom. The scientist presentation was great background knowledge." (Quote from postworkshop survey)

Workshop Participants

Workshop surveys showed that participating teachers came into the workshop with a good understanding of the basics of climate change and its attribution, as well as a general understanding of weather and climate, the Arctic, albedo, and concepts like positive and negative feedbacks (Table II). Participants also demonstrated a working knowledge of the nature of science, the basic principles of data display and analysis, and quantitative reasoning. The postworkshop survey indicated that the baseline performance of the workshop participants increased across all categories of the survey (Table II). Open-ended responses to questions about scientific basics like the definition of the Arctic or reasoning about albedo effects were more detailed and increased in scientific accuracy in the postworkshop assessment. The highest learning gains were achieved in the questions that addressed content knowledge (e.g., understanding of feedback mechanisms) and reasoning about topics covered in the workshop (e.g., interpretation of satellite images depicting albedo value changes over time). The responses for the data analysis and quantitative reasoning skills improved only slightly. This is not surprising, because the condensed activities did not allow time to practice data plotting and data analysis in the depth that the full curriculum offers, leaving minimal time to improve skills in this area (Table II). Based on preworkshop survey responses, the educators were mostly interested in learning how to teach about climate change and wanted to include data-rich and technology-focused activities in their science curriculum.

When asked about the best parts of the workshop, workshop participants expressed enthusiasm for the classroom-ready activities (67%) and the opportunity to partake in the activities themselves (29%; see also Table III). The participants stressed that pedagogic approaches offered in the curriculum, such as jigsaw and group work, were helpful and allowed them to build confidence in their ability to implement these instructional techniques (29%). The participants reflected that they also appreciated the ample discussion time about implementation strategies with other teachers in small, grade-level–focused groups, as well as the opportunity to provide feedback on the new curriculum (33%). Many workshop participants mentioned the quality and value of the scientists' presentation (38%). Throughout the workshop, participants contributed recommendations for improvement of the curriculum. For Module 1, they suggested having students zoom out from the Eureka site in order to get a better sense of the geographic location; for Module 2, they suggested adding a role-playing component for the data description; and for Module 3, they suggested improving the Excel instructions and including screenshots. These and many more suggestions were incorporated into the latest version of the curriculum. When asked how to improve the workshop, the majority of participants said that they wish there had been more time (54%) and that they would have liked more adaptation to grade levels (13%).

When asked which materials they were planning to implement in their classes, most educators listed several activities. Some teachers intended to implement most of the curriculum in the coming school year (21%), while others only planned to only use the data-rich and Excel-based activities (50%), the Google Earth activity (38%), the glacier image comparison (21%), and/or the hands-on activities (17%).

The workshop presenters found the participants to be engaged in the materials and focused on their learning. Both workshop presenters found the discussions about implementation strategies and practical classroom issues lively and engaging:

> *"[Workshop participants] just focused in on the workshop activities and played along in the mock implementation. We emphasized many times that their input counted and it must have been genuine enough that all teachers really felt they could suggest improvements and share their views."* (D. Morrison, reflection survey)

While the participants engaged well with the activities from the curriculum, both presenters reported that some of the teachers struggled with the technology, like basic computer handling, Google Earth, and Excel. Based on observations from the workshop, the curriculum developers further refined the step-by-step instructions to provide the educators with enough tools to teach with the technology.

Classroom Implementation

Following the workshop, some participants implemented part of the curriculum. Of the 26 teachers, 11 provided feedback about how they implemented the activities, the context and level of student engagement, and suggestions for improvements. The teachers reported on implementation with over 1,100 students between March 2014 and March 2015.

The overall feedback was positive. Many of the teachers (64%) reported that their students were engaged throughout the activities and were curious about the topics. Teachers stressed that interesting discussions and follow-up questions were prompted by the curriculum (10%), such as the impacts of melting glaciers. The students enjoyed the hands-on activities; the albedo measurement was reportedly more fascinating to students than soil temperature and relative humidity measurements. The introductory videos, especially the one about the impact of climate change on native Arctic people, were powerful hooks for discussion. Some lower-ability middle and elementary school students struggled with reading level of the materials (18%), both in the step-by-step instructions and in the Web-based research. This is not surprising, since the student guide is written at a high school reading level (grade 10–12, Flesch-Kinaid readability index). One teacher explained that she supported the struggling students individually and was planning to group students by ability in order to encourage lower-ability students to engage without relying on the advanced students. Middle school students were more engaged if the teacher started out with a whole-class introduction before diving into group work. From high school teachers, we heard that students connected with the exploratory nature of the curriculum. Two middle school teachers reported that, overall, boys were less engaged than girls, cautioning that this pattern is typical for the grade level and classroom. Some teachers (18%) mentioned that engagement was based on the ability level of the students, with the higher-ability students being more engaged than lower-ability students. However, overall the engagement was high compared to the typical engagement of students. When asked which of the suggested pedagogic approaches teachers used in their classes, 64% said that they used group work, 36% used a proposed jigsaw approach, and 18% mentioned using classroom discussions.

DISCUSSION

While the NSF's Broader Impact criterion has received increasing emphasis in the funding distribution in recent years (NSF, 2015b), some scientists have been questioning whether funding of research should be tied to outreach and education activities that require scientists to become experts in the outreach field (Holbrook, 2005; Tretkoff, 2007; Alpert, 2009; Frodeman and Parker, 2009; Lok, 2010). The collaborative model that we are proposing here allows educators and curriculum developers to take leading roles in creating Broader Impact products for research projects, with the scientists serving as advisers and mentors. These roles do not require strong outreach expertise or a large time commitment from the scientists. In the proposed collaborative model, the scientists contribute the science expertise, the research project, and the data, whereas the curriculum developers bring their skill of translating science concepts in an approachable sequence of activities and information that scaffolds the learning process effectively. The third group of collaborators in the model, the classroom educators, provides input and feedback from their work with students in the classroom. Once trained in a curriculum, educators serve as multipliers of knowledge—reaching many students each year. The proposed collaboration model provides a way to broaden the impact of a research project through the development of high-quality, classroom-ready curricular materials through a collaborative process.

The true integration of scientific practices with learning science content is a key concept of the NGSS for good reason. It requires new approaches to curriculum development that focus on the integration of scientific practices and content and provides teachers with sufficient support to teach the scientific process and the use of authentic data in the classroom. While educators are mandated through the NGSS to include scientific data in their teaching, apply inquiry-based teaching approaches, and expose students to the scientific process, educators without a science degree may lack the proficiency to carry out that objective. Even educators with a science degree may have incomplete understandings of scientific practices due to their limited experiences with true scientific inquiry (Windschitl, 2004; Houseal et al., 2014). Teachers might also not be proficient in using data analysis tools or programs. For example, our preworkshop survey revealed that only 12% of respondents teach with Excel in their classes two to three times per month or more, and more than 50% report that they have students create graphs infrequently (once per month or less). Excel, while a useful and nearly universal tool, can be intimidating for educators and students alike, as discussed repeatedly by workshop participants. Based on this feedback and workshop observations, the curriculum developers provided a lot of scaffolding and created instructions that are both written and visual through screenshots. These detailed instructions and partial solutions allow the educator to adapt the rigor of the activity to the student ability. While advanced students can work with open-ended and exploratory prompts, students who struggle with the basics of the data processing tools or basic understanding of data can work through clear instructions or gain insights from partial solutions along the way.

A curriculum appeals to many different learners if it includes a variety of activities and teaching approaches. Data from a national survey of 220 educators on their experiences in teaching climate topics indicate that the majority of students are excited to participate in activities that include hands-on activities (80%), followed by using scientific datasets (40%), using real scientific technology (37%), studying local issues (40%), and working with visualizations (41%; Lynds and Merryman, 2012). Using these results as guidance and striving to appeal to different learners, the curriculum is organized to have students conduct their own collection of meteorological data before working with the existing authentic meteorological data. Thus, students develop an appreciation for data collection challenges and practices, allowing them to translate their own experiences into their analysis of climate datasets. The reflections of our implementing teachers show that the variety of resources around data use–facilitated student engagement.

To allow for implementation in a range of classroom settings and grade levels, we also varied the degree of challenge in different segments of the curriculum. While curriculum developers and educators can often be most invested in the more rigorous aspects of the curriculum, educators were frequently reminding the curriculum developers to build in lead-in activities and supporting materials that allow teachers to ramp up to the challenging activities. Every module includes a set of basic questions but then leads to higher-order thinking questions that require advanced reasoning. Furthermore, each module includes optional extension activities that allow for more in-depth exploration and application of the concepts. This scaffolded rigor of the materials allows for differentiated instruction in a mixed-ability classroom, where the advanced students can work on additional questions while others might receive support in developing a working understanding of the materials.

Receiving detailed feedback from in-service classroom teachers was illuminating for the curriculum developers and is a key component of the proposed collaborative model. Implementation feedback was geared toward the enactment in the classroom and implementation tips, leading the curriculum developers to revisions that addressed the classroom organization and management. Issues like the use of ink-intensive images and excessive photocopying were reminders about real-world usability.

The workshop evaluation showed that participants appreciated the interactions with the scientists, both through the formal presentation and through the informal opportunities to ask questions. In individual conversations, some shared that they had never interacted with a scientist. Others commented that hearing a presentation from a field scientist who collected the data they were just exploring and who had been to the measurement site at the Arctic research site they had just "visited" using Google Earth made it easier to relate to the data. Many said they planned to replay part of the recorded presentation to their students to recreate the same connection to the scientists that they felt. These teacher excerpts show that the scientists themselves made a broader impact, not just in providing data for the curriculum but also in being willing to engage with the workshop participants. The educators serve as multipliers and can reach students by sharing their experience. Engaging in education and outreach and supporting the development of high-quality curricula are fruitful ways for scientists to engage with the public.

The process we report here has some limitations. The feedback provided by both the workshop participants and the implementing teachers was based on self-report, open-ended information instead of observer data or student assessment. The classroom feedback stems from 11 teachers who implemented the curriculum with about 1,100 students; a larger sample size would be beneficial. Next steps will include implementing the full curriculum in additional classrooms, collecting data on student learning gains, and performing classroom observations.

CURRICULUM DISSEMINATION

The ACC curriculum is freely available online under a Creative Commons license (Cooperative Institute for Research in Environmental Sciences, 2015). Educators can select from classroom-ready PDF files or modifiable documents in Microsoft Word format. A presentation by the research scientist about the Arctic (Arctic Research, Earth's Energy Budget) and research findings are available both on the project Web site (available at: http://cires.colorado.edu/education-outreach/projects/current-projects/arctic-climate-connections/) (including time stamps for subsections) and on YouTube.

The curriculum is also included as part of the extensive online collection for teaching climate change at the Science Education Resource Center at Carleton College (Manduca et al., 2010). Each of the Web pages that follow describes one module of the curriculum and discusses context for use, learning goals, teaching tips, and assessment strategies:

- Module 1: http://serc.carleton.edu/NAGTWorkshops/climatechange/activities/82345.html
- Module 2: http://serc.carleton.edu/NAGTWorkshops/climatechange/activities/82294.html
- Module 3: http://serc.carleton.edu/NAGTWorkshops/climatechange/activities/82303.html

Information about the curriculum was also disseminated to national e-mail lists that serve educators who are interested in teaching about the climate and the Arctic. In addition, the activities are under review by the Climate Literacy and Energy Awareness Network (CLEAN; Gold et al., 2012) for inclusion in the CLEAN collection.

Web statistics from the project Web page show that traffic has been increasing during 2014, with the peak visitation in May. Over 33% of the traffic has been from Colorado Internet service providers, and around 10% has been from California and Kentucky. There have been visitors from 29 states in the U.S. to date. Most of the traffic has arrived at the Web site via a direct link (bookmark or directly entered address); about 25% of visitors have arrived via a Google search. New visitors comprise just over half the total, with returning visitors making up the rest.

CONCLUSION

Many scientific issues are relevant to public policy; thus, a scientifically literate citizenry is an important goal for educators. The NSF's Broader Impact requirements can help with this process, but it can be challenging for scientists to engage directly with the public. Thus, a collaborative process can bring authentic research to a wide audience, with materials that are specifically designed to resonate with its audience.

Educators are excited about bringing real science into their classrooms, especially if materials easily integrate in their teaching. Scientists are mandated to share their research findings with the public and contribute to education. Our curriculum design presents key concepts in a scaffolded manner that builds complexity gradually. Using the proposed model, we developed a curriculum that brings Arctic climate research into secondary classrooms and that was developed as the Broader Impacts effort of a science research project.

The broad goals of the curriculum project were to engage students in working with authentic scientific data and learn about the nature of science. The materials focus students' attention on current scientific research going on in the Arctic and how work done in the Arctic is relevant to their lives and the global climate.

The collaborative curriculum development process involved research scientists, curriculum developers, and classroom teachers in an iterative process. The curriculum was tested with 26 Colorado educators in a professional development workshop, and teaching materials were revised based on their feedback. The collaborative process was described as effective and satisfying to all three groups. Classroom implementation and formative feedback from all three groups indicates the collaborative model for development and dissemination of the ACC curriculum holds promise for engaging scientists, teachers, and students alike. Workshop participants expressed their excitement for the data-rich curriculum and are in the process of implementing the curriculum in their classrooms. Working with unprocessed data provides many teachable moments of discussing data collection and instrument calibration issues forms an appreciation of field-based data collection and the scientific process. Initial results from the classroom implementation with over 1,100 students suggest that students are engaged, especially through the active learning techniques. Implementation results show that the hands-on albedo activity, Google Earth, and the data activities are interesting for students but that they also enjoy the supporting videos.

Educational experiences such as this collaborative curriculum development have the potential to build connections between remote scientific research and everyday experiences of teachers and students, illuminate aspects of climate science for a broader audience, and excite students about the nature of scientific advancement. This curriculum builds upon and joins the efforts of many other educators and scientists as part of an increasingly important endeavor to increase the science literacy of students and the public.

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